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ORIGINAL PAPER

The impact of land afforestation on carbon stocks surrounding Tehran, Iran

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Abstract: The city of Tehran, like many polluted metropolises of the world, has higher emissions of greenhouse gases than other cities in Iran, due to heavy consumption of fossil fuel and landuse changes. To estimate carbon sequestration in two 40 year-old stands of planted *Cupressus arizonica* and *Fraxinus rotundifolia* in degraded lands surrounding Tehran , sampling of above- and below- ground biomass, soil (at two depths of 0–15 and 15–30 cm), and leaf litter was done by systematic random sampling. The total carbon stocks of *C. arizonica* and *F. rotundifolia* stands were respectively 328.20 and 150.69 $Mg \cdot ha^{-1}$. The aboveground biomass with 233.16(71%) $Mg \cdot ha^{-1}$ in *C. arizonica* and 88.16 (58.50%) $Mg \cdot ha^{-1}$ in *F. rotundifolia* contributed the most shares to carbon sequestration. The diameter at breast height, total height, basal area, total volume, and biomass of *C. arizonica* were significantly (p <0.01) higher than those of *F. rotundifolia*. Also the depth of 0–30 cm of soil contributed between 18.29 % and 32.15 % of total ecosystem carbon, respectively. The economic value of carbon sequestration in the two stands in 2011 was calculated at 3.5 and 2.5 million dollars, respectively. Our results indicate that afforestation of the degraded land surrounding Tehran would sequester more carbon than would continuously degraded land, the current status quo. These stands can absorb atmospheric CO_2 at different rates, thus tree species selection and stand development should be considered in planning future afforestation projects.

Keywords: carbon sequestration, afforestation, *Cupressus arizonica*, *Fraxinus rotundifolia*, Tehran.

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Introduction

Carbon sequestration through afforestation is one of the most appropriate methods to balance the CO_2 emissions (Davis and Condron 2002; Smith 1999) to prevent global warming (Watson 2000; IPCC 2001). Many studies of afforestation and its influence on ecosystem carbon stocks have been reported in recent years (Grunzweig et al. 2003; Wauters et al. 2008; Stevens and Wesemael 2008; Varamesh et al. 2010).

Expanding plant coverage through afforestation results in greater absorption of atmospheric CO_2 through photosynthesis; it separates its carbon and oxygen atoms, releases the oxygen back to the atmosphere and uses the carbon to produce the biomass, namely root, stem, branch, and leaf (Kerckhoffs and Reid 2007). Apart from aboveground biomass, tree roots, litter, and soil also contain measurable carbon stocks (Johnson et al. 2003; Oliver et al. 2004).

Although the effect of afforestation on carbon sequestration of biomass is clear (Arevalo et al. 2009, Redondo-Brenes and Montagnini 2006; Mendham et al. 2003), the effect of afforestation on soil carbon stocks is not significant (Jackson et al. 2002; Varamesh et al. 2010). Scott (2000) stated that the most important factors that determine changes in soil carbon due to afforestation are the soil type and its previous use. Davis and Condron (2002) also indicated that total carbon stock of soil depends on the balance between input and output of carbon. Changes in the quantity and quality of microorganisms in the

detrital layer can also affect soil carbon stock (Lemma et al. 2007).

The limits of our knowledge are due to our lack of understanding of survival, biology of fine roots, microorganism's reactions, and availability of nutrients and coefficients of various echo-physiological processes such as carbon and nitrogen cycles and their below-ground component (Ceullemans et al. 1999). Selecting the species is a main decision in management that has an important effect on carbon stock in forest ecosystems (Vallet et al. 2009).

We chose to focus on two species, *C. arizonica* and *F. Rotundifolia,* that are common species in afforestation of vast areas of Iran. The purpose of this research is to estimate the carbon sequestration of the 40-year old stands of *C. arizonica* and *F. rotundifolia* that were planted on degraded lands surrounding Tehran and to determine the share of each ecosystem component in carbon sequestration. Furthermore, the most important physical and chemical factors influencing soil organic carbon will be defined and the economical values of this afforestation in carbon sequestration will be estimated.

Materials and methods

Study area

The study area is located west of Tehran with an area of 900 hectares (along the Tehran-Karaj highway) in Chitgar forest park, located between 51°10′ and 51°15′ eastern longitudes and 35°42′ and 35°45′ northern latitudes (Fig. 1). This park was established in 1969 to reduce air pollution, create a green belt around Tehran, clear the air, provide entertainment and recreational facilities, and prevent the undesirable expansion of the city.

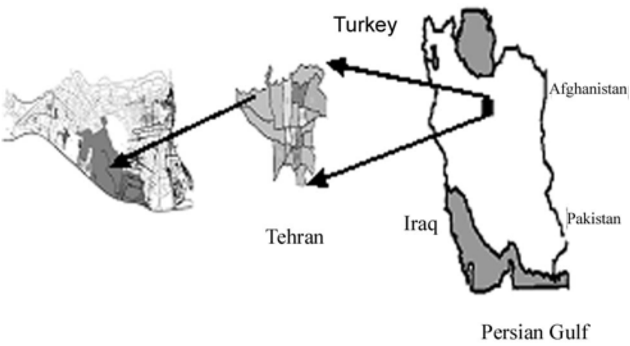

Fig. 1. The location of study site

The area has an arid Mediterranean climate. The altitude is 1300 m a.s.l. and the mean annual precipitation is 232 mm. The soil texture is loamy-sandy. Out of the total, 6% of the planted area is covered with *C. arizonica* and 10% is covered with *F. rotundifolia*. Due to low annual rainfall, the forest stands have been under irrigation at the rate of 5000 m^3 per hectare for 6 months of the year and almost every 20 days once irrigation has been done.

Sample processing

Two stands, including *C. arizonica* and *F. rotundifolia* species with 10 ha in area, were selected and the surrounding degraded lands were used as control. To decrease the boundary effects, some surrounding rows of stands were not considered for sampling. Then at each stand, nested plots were picked by systematic random sampling. At first, in 10 m ×10 m plots, several measurements were taken, including diameter at breast height (DBH), tree height (H), height to the base of the crown (Hc), and diameter of canopy or crown in two perpendicular directions, termed here for convenience “length” (L) and “width” (W). At each stand, 10 trees were randomly harvested and a 5 cm slice of wood was taken from the bottom of each 2 m bole section.

Branches were cut and their weight was measured. The branches were then cut into 5 cm pieces and 10 samples were picked randomly. In each 5 m × 5 m plot, the leaf litter layer was removed and soil samples were taken from two depths, 0-15 cm and 15–30 cm. To minimize error, the bulk sampling was done in this way so that 4 soil samples were taken from the four corners of the plot and then the samples were mixed together. At the end, all of the existing leaf litter was also collected and weighed from a 1 m ×1 m plot. Samples of each component were pooled, sealed in plastic bags, and transported to the laboratory (MacDicken 1997; Losi et al. 2003; Hernandez et al. 2004; Redondo 2007; Varamesh et al. 2011).

Calculation of biomass

To calculate tree biomass and to compute trunk, canopy and root volume followed steps were done according to prescription (Hernandez et al. 2004). First, the basal area of tree was computed using Eq. 1, and second, the tree volume was gained using Eq. 2. And third, the biomass of trunk (kilogram) was computed according to equation 3.

$$Ab = \pi x r^2 \tag{1}$$

where: π= 3.1415927; and r is the radius of the tree at breast height (0.5 DBH).

$$V = Ab \times H \times Kc \tag{2}$$

where: Ab is the basal area; H is the height; and Kc is a site-dependent constant in standard cubing practice used in forest inventory (0.5463).

$$Biomass = V \times WD \times 1000 \tag{3}$$

where, V= volume of the trunk, WD= wood density.

100% inventory of tree roots need time consuming, and is expensive, and degradative work, so the root volume was calculated using equation number 4 (Hernandez et al. 2004),

$$BGB = VolumeAGB \times 0.2 \quad (4)$$

where, BGB = Belowground biomass; AGB = Aboveground biomass.

The canopy volume of *C. arizonica* with equation number 5 and the canopy volume of *F. rotundifolia* with equation number 6 were computed.

$$V\left(m^3\right) = \Pi \times \left(\frac{Db^2 \times Hc}{12}\right) \quad (5)$$

$$V\left(m^3\right) = \frac{\Pi \times Db^2}{12} \quad (6)$$

where, π = 3.141592; Db = diameter of the crown canopy (to calculate Db, the average of the field measurements L and W is taken and used as the diameter of the crown: $Db = (L + W)/2$); Hc = height from the ground to the highest point of the crown.

Laboratory methods

The trunk, branch, root, and litter samples were dried within 24hours at 105°C and then the percentage of organic carbon was measured by burning it in an electrical oven (MacDicken 1997; Birdsey et al. 2000; Losi et al. 2003). Density of the root, trunk, and branch samples was calculated using the dry weight density. Soil samples were dried in open air and broken into pieces. After separating the roots, stones, and other gross materials, the sampleswere ground and sieved through a 2mm sieve (mesh 20). The percentage of stones in the soil samples was calculated.

The soil texture was determined by the Bouyoucos hydrometer method (Bouyoucos 1962). The water content at saturation level (%) was also measured. Soil pH was measured using a pH meter (Orion Analyzer Model 901) in a suspension with a soil:water ratio of 1:2.5.

Total nitrogen was measured using a semi- Micro-Kjeldhal technique (Bremner and Mulvaney 1982). The bulk density was determined volumetrically (g/cm³) by using the cold method (Blake and Hartge 1986). To measure the organic matter and organic carbon, cold method based on organic carbon oxidation with potassium bichromate in a completely acidic environment (H_2SO_4) according to the following equation was done (Allison 1975):

$$8H_2SO_4 + 3C + 2K_2Cr_2O_7 \Longleftrightarrow 2K_2SO_4 + 2Cr_2(SO_4)_3 + 3CO_2 + 8H_2O$$

Statistical analysis

First, normality was determined with through a Kolmogrov-Smirnow test and the homogeny of variances were investigated using the Levene test. For general comparison of the stands from the view point of soil characteristics, a one-way ANOVA test was conducted. To compare the means, aTukey test was applied. To define the most important soil factor that influences the soil organic carbon amount, stepwise regression was used. To compute the allometric equations of tree species, two variant and multi-variant regressions were used and appropriate equations with acceptable statistical indicators were introduced.

Results

The results showed that the *C. arizonica* stand had 328.2 Mg·ha^{-1} carbon sequestered over the 40-year period, with 56.5% of this amount stored in the trunk, 14. 6% in branches, 9.46% in roots, 18.3% in soil, and 1.21% in the litter of this stand.

The *F. rotundifolia* stand sequestered 150.69 Mg·ha^{-1} carbon over 40 years of which 50.1% is stored in trunk, 7.6% in branches, 8.2% in roots, 32.15% in soil and 1.1% in the litter of this stand. it had no plant cover and only 10.80 Mg ha^{-1} carbon stored in the soil (Figs. 2 and 3).

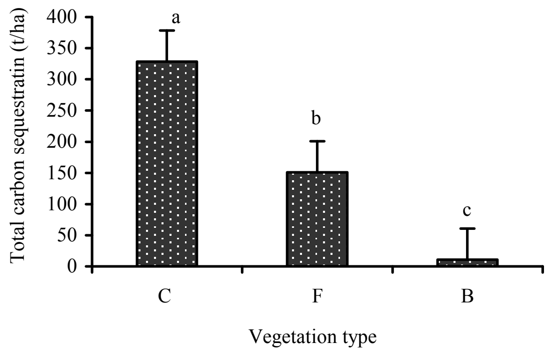

Fig. 2. Total carbon sequestration under various stands. C = *C. arizonica*; F = *F. rotundifolia*, B= degraded land

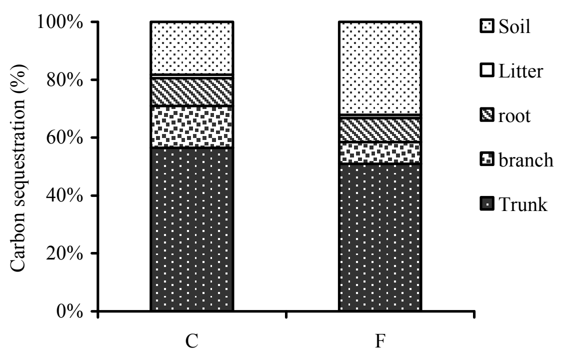

Fig. 3. percentage of carbon distribution among trunk, branch, root, litter and soil in *C. arizonica* (C) and *F. rotundifolia* (F) stands

The stock of soil organic carbon at the two depths, 0−15 cm and 15−30 cm in the two stands showed that percentage of organic carbon at depth 0−15 cm of *C. arizonica* is higher (Fig. 4). Results of regression analysis of organic carbon versus other tested soil properties showed that the ratio of carbon to nitrogen (C/N) and nitrogen content were respectively the most important factors affecting soil organic carbon. The other investigated characteristics had no significant effect on soil organic carbon (Table 1).

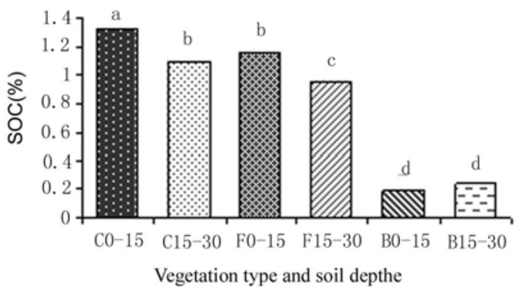

Fig. 4. Soil organic carbon (SOC) contents in tow depth under various vegetation types. C = *C. arizonica*; F = *F. rotundifolia*, B= degraded land

The results of regression analysis indicated that there is a linear relationship between soil organic carbon (dependent variable) and soil characters ($Y= 0.34+2.3X_2 \times 10^{-2} X_1$, R^2=50.8).

where: Y: the amount of Soil Organic Carbon, X_1: C/N, X_2: Nitrogen.

Investigation of some quantitative characteristics of the two planted stands also indicated that almost all of them showed significant difference (p <0.01). The values of DBH, basal area, total height, trunk volume, canopy volume, root volume, branches biomass, trunk biomass, and root biomass for the *C. arizonica* stand were higher than for the *F. rotundifolia* stand (Fig. 5). The densities of the two stands were respectively 916 and 700 trees per hectare.

Comparison of carbon sequestration content in the two stands showed that the amount of carbon sequestered in soil, leaf litter, trunk, roots and branches of the two stands were significantly different (p<0.01); in the *C. arizonica* stand, the values were higher than in the *F. rotundifolia* stand (Fig. 6).

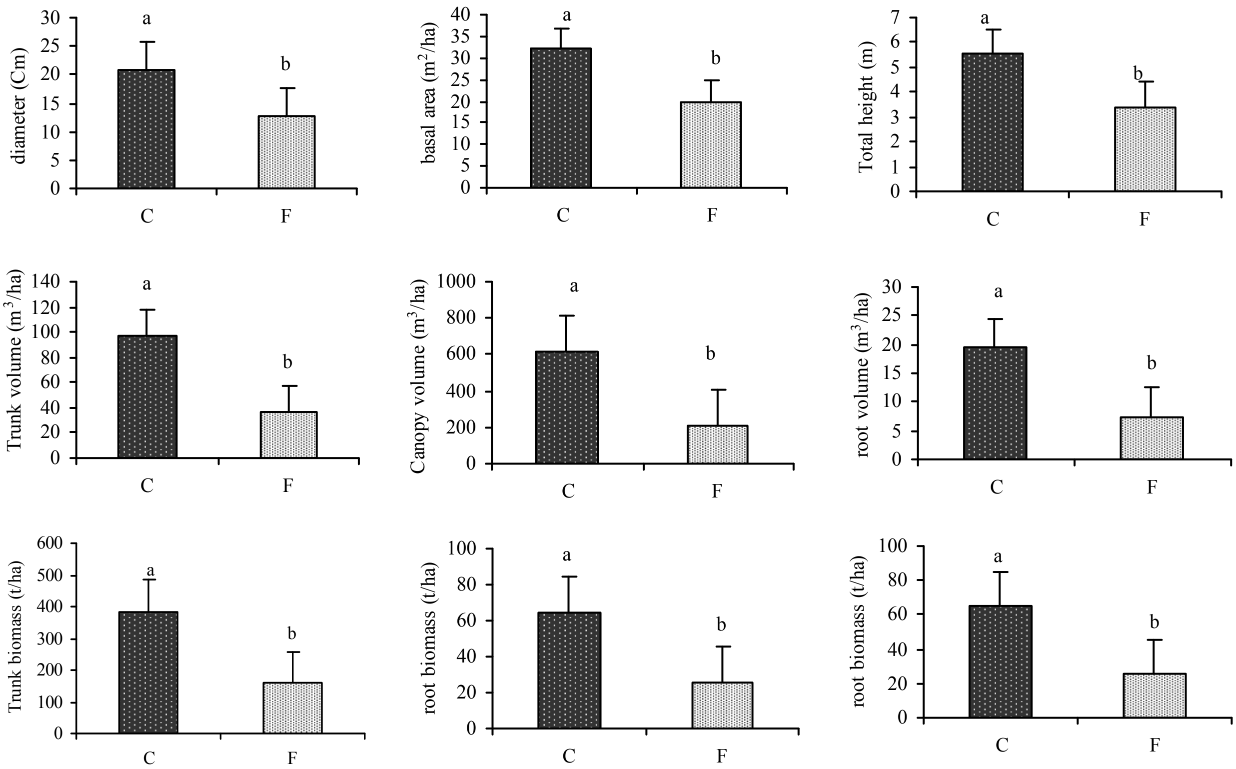

Fig. 5. General growth and productivity statistics of *C. arizonica and F. rotundifolia stands* at Chitgar forest park of Tehran, Iran

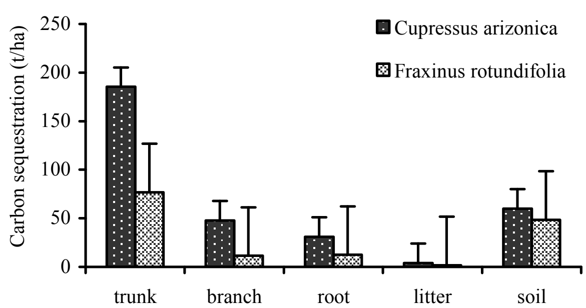

Fig. 6. Carbon sequestration in above and belowground biomass of *C. arizonica and F. rotundifolia* stands

Related allometric equation to biomass

The most suitable equations that were presented for *C. arizonica* and *F. rotundifolia* in the study area are shown in Tables 1 and 2.

Table 1. Allometric equations for *C. arizonica* biomass

regressions	Equations	R^2
Linear	Y= -12.95 + 30.08d	0.94
Expontial	$Y = 221.28 * e^{0.048\, d}$	0.93
Logarithmic	Y = -1258 + 619.11 log d	0.92
Stepwise	Y = -611.42 + 29.80d + 109.29 h	0.99

Y= total biomass (kg), d= DBH (cm), h= total height (m)

Table 2. Allometric equations for *F. rotundifolia* biomass

regressions	Equations	R^2
Linear	Y= -31.27 + 25.60 d	0.89
Expontial	Y= 97.55 * $e^{0.085\ d}$	0.88
Logarithmic	Y= -534.32 + 327.57 log d	0.88
Stepwise	Y= -293.37+ 23.29 d + 85.79 h	0.99

Y= total biomass (kg), d= DBH (cm), h= total height (m)

Discussion

This study proved that reclamation of degraded lands with *C. arizonica* and *F. rotundifolia* species plantation has a high potential for carbon sequestration. Jackson et al (2002) and House et al (2002) also have underscored the importance of re-cultivation of degraded lands as an appropriate way to reduce the accumulation of atmospheric carbon. The more content of carbon sequestration in *C. arizonica* stand than *F. rotundifolia* can be attributed to more stock of this stand in area unit (Hoover et al. 2000).

Distribution of total carbon sequestration also showed that carbon stock in aboveground biomass is more than ground biomass, which conforms to the results in Aradottir et al. (2000). In addition, the share of biomass in the carbon stock of trees changes over the forest stands‘ lifespan (Satoo and Madgwick 1982).

Honda et al. (2000) also state that almost all methods to estimate carbon sequestration are based on biomass inventory. As to the total carbon stock of different forest stands, there is a direct relationship between stored carbon and species, growth, site fertility, silvicultural and management activities (Redondo 2007). The higher volumes of carbon sequestration in the leaf litter in *C. arizonica* stand than *F. rotundifolia* may be due to the lower rate of decomposition in this stand (IPCC 2000). Leaf litter production depends on important factors such as species, climate, and growth site fertility and production ability in such a manner that various values are reported for different species in different growth conditions.

Furthermore because of lower production in the *F. rotundifolia* stand, the content of leaf litter in this stand was also lower than in the *C. arizonica* stand. Litter production and root decomposition, especially fine roots, are important processes that influence the soil carbon stock (Steele et al 1997). In this research, the low litter production and root volume in the *F. rotundifolia* stand can be counted as an acceptable reason for lower carbon sequestration in the *F. rotundifolia* stand than *C. arizonica* stand. Besides soil carbon sequestration has a great importance to reduce the climate changes (Rossi et al 2009). Dinakaran and Krishnayya (2008) stated that the type of plant coverage has significant effect on soil organic carbon, the prime example being soils with dense tree coverage that show high levels of organic carbon.

The results of our study showed that the effect of nitrogen on soil organic carbon(Alard et al. 2007). The soil texture and abundance of microlithic particles of soil are important characteristics of soil carbon changes in the of mentioned areas (Qing-Biao et al. 2009). The soil organic carbon changes are influenced by important factors like climate, plant coverage, and soil texture (Peng et al. 2004). The amount of carbon stock in various forest stands depends on species and the rate of crop. Commonly, the amount of carbon sequestered quickly increases with crop growth but, in the long term, the amount of carbon sequestered can not be highly dependent upon growth (Our results show that tree roots were one of the most important components of carbon sequestration in forest stands (Laclau 2003): this amount in the *C. arizonica* stand was greater than *F. rotundifolia* stand. Vedrova (2005) also reported that the root carbon stock in softwoods is greater than in hardwoods.The quantification of carbon stock information is very useful to define the value of important environmental services (Sandra 2000).

The results showed that about 54 ha (6%) of the total study area is covered with *C. arizonica* and 90 ha (10%) is covered with *F. rotundifolia* stand. Also, forest plantations with these two species demonstrated 317.4 and 140 t carbon sequestration in comparison with degraded land, respectively. Mentioned planted stands have respectively increased the carbon sequestration 17139.6 and 12600 tonnes in comparison with surrounding degraded land.

Considering that 27% of CO_2 weight is carbon, a tonne of sequestrated carbon equals 3.7 t of atmospheric CO_2. Therefore the mentioned stands have respectively sequestered some 63416.52 and 46620 t of CO_2.

Industrial air purification like filtering would demand highcosts (Cannell 2003). Cannell et al (1995) has reported this amount about \$200–300 for each tonne of carbon in America. Luciuk et al. (2000) also estimated the value of carbon sequestration per tonne at about \$348−790, counting the land-rent expenses.

If we consider US \$50 as the reasonable amount (Pablo et al. (2003) per tonne of carbon in the studied plantations, the economic value of carbon sequestration with *C. arizonica* and *F. rotundifolia* will be 875 and 625 thousand dollars, respectively.

The results of such plantings may differ as Schuman et al. (2002) explained due to climate, topography, soil characteristics, plant community composition, and various management activities. Therefore in order to increase the carbon sequestration the applicable alternatives of ecosystem management should be confirmed on three aspects of soil, biomass and litter.

Given that making changes to soil and leaf litter is not practical, the only direct change that is feasible is biomass management. For this reason, in many carbon sequestration projects, proper ecological management activities have been implemented to increase biomass production and to prevent land degradation.

Conclusion

In Iran, the carbon sequestration potential of forestry plantations has been an important issue during recent years. The results of

this study have once again demonstrated that carbon stocks potential differs with plant species, location and management methods. The identification of the species with higher capability for carbon sequestration and implementation of the management activities that affect the sequestration process can assist with formulating land reclamation strategies. These considerations can potentially make the reclamation and re-cultivation of degraded lands an economically viable solution to mitigation of land degradation and climate change and finally provide an opportunity to achieve sustainable forestry.

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